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10.1 GENERAL

The function of a foundation is to transfer the load from the superstructure to the soil and/or rock without objectionable settlement. Selection and design of the proper foundation is dependent on the materials at the site, interpretation of field data, results of laboratory tests and engineering judgment. Avoid deep foundations if possible since their cost increases significantly with depth. However, when surface soils are too weak, the foundation must be carried down to more resisting layers. Depending on site conditions, this is accomplished by open excavation, driving piles or with caissons. Traditionally, bridge structures have utilized pile units to carry loads down to more resisting materials. Pile types most commonly used in Wisconsin are cast-in-place or steel H-piles.

At a majority of structure locations, the abutment type selected rests on newly compacted fill. To preclude settlement at the abutments, it is recommended that piles penetrate into natural ground. When the fill material is in excess of 10 feet (3 meters) of height, preboring for a displacement type pile is generally required.

In the case of stream crossings where a sill abutment is employed, pilings are recommended and driven to a minimum penetration of 10 feet (3 meters) below streambed, unless resting on solid rock. For stream crossing structures with sill abutments, when the materials on which the abutments rest are subject to stream currents or erosion, piling is required. In general, the recommended penetration of any pile is not less than 10 feet (3 meters) in hard material. The recommended penetration when only soft material is available is not less than one-third the length of the pile nor less than 20 feet (6 meters). For permanent foundations, do not terminate piling in a soft upper stratum when a hard layer is below. The piling should penetrate the hard layer a sufficient distance to rigidly fix its ends.

A change in spread footing elevations from plans on grade separation structures of 1 foot (300 mm) deeper or 3 feet (900 mm) shallower does not require redesign. All spread footing elevation changes from plans on stream crossings should be checked for scour conditions.

10.2 SOIL CLASSIFICATION

The total weight of the bridge plus all of the forces imposed upon the bridge are carried by the foundation soils. There are many ways to classify these soils for foundation purposes. An overall classification follows:

1. Bedrock - There is igneous rock as granite, etc.: sedimentary rock as limestone, sandstone, and shale; and metamorphic rock as quartzite or marble.

2. Glacial Soils - This wide variety of soils includes granular outwash, hard fills, bouldery pot hole areas and almost any combination of soil that glaciers can create.

3. Alluvial Soils - These are found in flood plains and deltas along creeks and rivers. In Wisconsin these soils normally contain large amounts of sand and silt. They are highly stratified and generally loose. Pockets of clay are found in backwater areas.

4. Residual Soils - These soils are formed as a product of weathering and invariably reflect the parent material. They may be sands, silts or clay.

   Limestone and shales form clayey soils. Sandstones and granite form sands or silts.

5. Lacustrine Soils - These are soils that are formed by sediment from the water. In Wisconsin, they tend to be clayey. The worst soils of the state are red clay sediments around Lakes Superior and Michigan.

6. Gravel, Cobbles and Boulders - These are particles that have been dislodged from bedrock, then transported and rounded by abrasion. Some boulders may result from irregular weathering.

Irregardless of how the materials are formed, the structure finally rests on bedrock, gravel, sand, silt, or clay or a combination of all these. So consider the principle soil types and how they act and differ.

1. Sand - The behavior of sand depends on grain size, gradation, density, and water conditions. Bearing capacity varies from almost nothing to 5 tons/sq. ft. (480 kPa) depending on density, grain size and embedment. Bearing capacities in sand increase materially with embedment. Sands scour easily so footings on sands must be protected in areas subject to scour.

2. Silt - This is a relatively poor foundation material with bearing capacities up to 4 tons/sf (380 kPa) in some areas. It scours and erodes easily and causes large volume changes when subject to frost.

3. Clay - This material needs to be investigated very closely for use as a bearing material. Bearing capacity depends on density, water content, cohesive strength, mineralogy and other factors. Bearing capacity varies from 0.5 ton to 4 tons/sf (48 to 380 kPa).

4. Bedrock - This is the best foundation material. Wisconsin has a lot of weathered rock. Weathered granite and limestone become sands. Shales and sandstone tend to weather more on exposure. Bearing capacities vary between different rock formations. Depending on degree of weathering, bearing capacities can vary from 2.5 to 100 tons/sf (240 to 9600 kPa).

5. Mixture of Soils - This is the most common case. The soil type that predominates behavior has the controlling name. For example, a soil composed of sand and clay is called sandy clay if the clayey fraction controls behavior. Soil capacity is determined by tests.

10.3 SOILS EXPLORATION

The Geotechnical Section prepares the Subsurface Exploration drawings and the Site Investigation Report. The drawings contain a study of subsurface conditions within the vicinity of the structure. All data relative to underground conditions which may affect the design of the foundation of the proposed structure are reported.

Soil exploration methods are generally classified into two groups which are Surface Survey and Detailed Site Investigation.

Surface surveys include studies of the site geology, air-photo review, and can include geophysical methods of exploration. Surface surveys provide valuable data indicating approximate soil conditions during the reconnaissance phase.

Based on the results of the Surface Survey information, the plans for a Detailed Site Investigation are made. First consideration is given to subsurface investigation which provides the following information:

1. Depth, extent, and thickness of each soil strata.
2. Soil texture, color, mottling and moisture content.
3. In situ field tests to determine soil parameters.
4. Laboratory samples for determining soil parameters.
5. Water levels, utilities, etc.

The number and spacing of borings is controlled by the characteristics and sequence of subsurface strata and by the size and type of the proposed structure. This is particularly true where rock is present. In some cases borings should be made at each substructure unit to adequately define conditions. Where it is apparent the soil is uniform, fewer borings are OK. District 7 Construction people have trouble with CIP piling due to coarse grained soils such as sand and gravel. We should require H piling for those cases. Borings are typically advanced to a depth where the added stress, due to the applied load, is 10 percent of the existing stress due to overburden or extended beyond the expected pile penetration depths. Where bedrock is encountered, borings are advanced by diamond bit coring to determine rock quality.

Second, any or all of the following soil tests may be considered necessary or desirable at a given site:

1. (F)* Standard penetration.

2. (F) Vane shear. (cohesive soils)

3. (F) Pocket penetrometer. (cohesive soils)

4. (F,L) Moisture, density, consistency limits and unit weight.

5. (L) Unconfined compression. (cohesive soils)

6. (L) Grain size analysis. (seldom used)

7. (F,L) One-dimensional consolidation. (seldom used)

8. (F) Cone penetration. (for cohesive soils, seldom used)

9. (L) Unconsolidated undrained triaxial compression. (seldom used)

10. (F) Bore hole pressure meter.

11. (F,L) Ph corrosive resistivity.

* F,L indicates field or laboratory testing.

One of the most widely used tests in the United States is the Standard Penetration Test (AASHTO T-206) as described in the AASHTO Materials Manual. This test provides an indication of the density or consistency of cohesionless soils and along with the pocket penetrometer readings approximate the strength of cohesive soils. Correlation between standard penetration values and the resulting soil bearing value approximations are available from many sources. Standard penetration values can be used to estimate pile friction values by experienced soils engineers by also considering soil texture, moisture content, location of water table, depth below proposed footing and method of boring advance.

For example, DOT soils engineers using DOT soil test information know that certain sand and clays in the northeastern part of Wisconsin have higher load carrying capacities than tests indicate. This information is confirmed by comparing test pile data at the different sites. The increased capacities are realized by increasing end bearing and/or skin friction values in the Site Investigation Report.

Wisconsin currently uses most of the soils tests mentioned. The soils tests used for a given site are determined by the complexity of the site, size of the project and availability of funds for subsurface investigation. Refer to a soils textbook for more detailed descriptions of soils tests.

Laboratory tests of undisturbed samples provide for accurate assessment of soil settlement and structural properties. Unconfined compression tests and other tests are employed to measure soil shear and unconfined compression strength and to estimate pile skin friction in clay soils by assuming:

$$f_s = c = \frac{qu}{2}$$

where, f_s = unit pile skin friction.
c = cohesion of soil.
qu = unconfined compression strength.

In addition to the tests of subsurface materials, a geologic study may be conducted to give such geologic aspects as petrology, rock structure, stratigraphy, vegetation and erosion.

Boring and testing data analysis, along with consideration of the geology and terrain, determine the following:

1. Whether the structure is founded on footings or piles.

2. If the structure is founded on footings, what the allowable bearing capacity versus settlement is. AASHTO allows 1 inch (25 mm) total settlement and 0.5 inch (13 mm) settlement between adjacent units.

3. If piles are required, what type is most suitable and what support value the soil furnishes.

4. Whether any problems affect construction.

5. Whether water conditions require seals, affect dewatering or cut slopes under abutments.

When piles are recommended, suitable pile types, length requirements, and design loads are discussed. Adverse conditions existing at abutments due to approach fills being founded on compressible material are pointed out and recommended solutions proposed. Safe allowable design loads at various elevations are given for footing foundation supports. Problems connected with scour, tremie seals, cofferdams, settlement and other conditions peculiar to a specific site are discussed.

For footings resting on rock place the following note on the plans:

Footings resting on rock are to be properly embedded in sound rock.

The important concept is getting a proper connection to sound rock. Sometimes it is not possible to get a deep embedment in granite or similar rocks.

10.4 SITE INVESTIGATIONS REPORT

Following is a sample of a site investigation report. The subsurface exploration drawing is also submitted with the report.

SITE INVESTIGATION REPORT
Project I.D. 1210-00-00
I.H. 43 over Kittycrest Drive
Structure B-5-265/266
Brown County

1. General

This site investigation report is for the twin structures which will carry I.H. 43, station 569± N.B. R_L, over Kittycrest Drive as part of the Syene Interchange. Approach fills are expected to be some 25 feet (7.6 meters) in height, and constructed of silty clays found throughout the area.

Abutment footing grades are anticipated to be at elevation 780 (238±), and the pier footings are expected to be at elevation 755 (230±).

The surface geology is that of glacio-lacustrine clay and silt deposits overlying limestone bedrock.

2. Subsurface Conditions

Six borings were made of the site. Standard Penetration Tests (AASHTO T-206) were made to estimate relative densities, maximum bearing capacities, and pile support values. Soil textures noted are driller's field identification with subsequent verification in the Geotechnical Section. Unconfined strength values shown are estimated from pocket penetrometer readings made on split spoon samples. Undisturbed Shelby tube samples were taken of the underlying soft clays to evaluate settlement properties and strength characteristics for an embankment study.

Soils were generally logged as soft to stiff silty clay, with occasional silt layers. A dense sand and gravel layer was encountered just above bedrock at elevation 660 (201±). Approximately a 15 foot (4.5 meter) surface crust of very stiff silty clay was found throughout the site. Limestone lies fairly uniformly across the site at elevation 650 (198±). Rock cores were taken with results as follows:

Boring Number	Core Size	% Recovery	Rod
1	AXL	70	40%
3	NXL	80/100	85%
5	NXL	100	95%

Water levels observed over a month period from the time of drilling indicate the water table to be at elevation 755 (230±).

3. Bearing Capacity

Footings placed in the upper portion of the surface crust could be designed for a bearing capacity of 2.5 tons/sf (240 kPa). Footings placed below elevations 750 (229±), however, should be designed for a maximum bearing capacity of 1 ton/sf (95 kPa).

4. Piles

The following values can be used for estimating pile lengths:

Elevation	Pile Skin Friction		% End Bearing	
	psf (kPa)	(SF=2)	(Displ. Piles)	(H-Piles)
Surface-745	800	38.3	25-30	15-20
745-695	400	19.1	10-15	___
695-660	600	28.7	15-20	10-15
660-650	800	38.3	50-60	25-30

H-piles driven to bedrock should be stressed to a maximum of 12 ksi (80 MPa) in the steel.

5. Caissons

While soil conditions are such that drilled shafts or caissons could be used, they do not appear to offer any advantages at this location.

6. Construction Problems

No particularly unusual construction problems are foreseen. Water table, however, will be near pier footing grades. Should spread footings be used, a minimum amount of time should elapse between excavation and footing construction. Excess moisture and too much reworking of this type soil can cause drastic soil strength reductions.

7. Embankments

Bridge end-slopes were analyzed by a computerized slope stability program utilizing Bishop's method, and the assumption of a circular failure arc. Results from this analysis show a factor of safety against failure of 1.1 for the proposed 2:1 slopes.

Settlement calculations indicate that total settlements on the order of 0.1 to 0.2 foot(30 to 60 mm) can be anticipated over a period of several years. Settlements of this magnitude occurring during this length of time will not cause excessive drag loads to develop on H-piles.

8. Recommendations

Spread footings appear to be the most suitable foundation type for the pier units.

A pile type foundation is suggested for the abutments. Economics should be the deciding factor as to whether to use a greater number of lightly loaded short displacement piles, or fewer, but longer, H-piles driven to bedrock.

Embankment settlement and end-slope stability are not anticipated to be problems. The actual factor of safety will be larger than the calculated value due to three dimensional effects. Settlements will be minimal, and should not adversely affect the structure.

10.5 TEMPORARY SHORING

1. General

This information is provided for guidance. Refer to the Facilities Development Manual for further details.

In general, Temporary Shoring should be shown on contract plans in all locations where it is needed to protect existing Transportation Facilities, Utilities, Buildings, or other critical features when safe slopes can not be made for structural excavations. Shoring may be required within the limits of structures or on the approach roadway due to grade changes or stage construction. Shoring should not be required nor paid for when used primarily for the convenience of the contractor.

2. When Slopes Won't Work

Typically shoring will be required when safe slopes can not be made due to geometric constraints of existing and proposed features within the available Right-of-Way. OSHA requirements for temporary excavation slopes vary from a 1.0/1.0 to a 2.0/1.0. The contractor is responsible for determining and constructing a safe slope based on actual site conditions. In most cases, the designer can assume that an OSHA safe temporary slope can be cut on a 1.5 to 1.0 slope, however other factors such as soil types, soil moisture, surface drainage, and duration of excavation should also be factored into the actual slope constructed. As an added safety factor, a one meter berm should be provided next to critical points or features prior to beginning a 1.5/1.0 slope to the plan elevation of the proposed structure. Sufficient room should be provided adjacent to the structure for forming purposes (typically 2.6 feet (0.8 meters)).

3. Plan Requirements

Contract plans should schematically show in the plan and profile details all locations where the designer has determined that temporary shoring will be required. The plans should note the estimated length of the shoring as well as the minimum and maximum required height of exposed shoring. These dimensions will be used to calculate the horizontal projected surface area projected on a vertical plane of the exposed shoring face.

4. Shoring Design/Construction

The contractor has full responsibility for the design of all shoring (required and elective) used on the project. The adequacy of the design should be determined by a Professional Engineer knowledgeable of specific site conditions and requirements.

A signed and sealed copy of proposed designs must be submitted to the Project Engineer for information.

5. Payment

| Payment of temporary shoring will be made at the bid price per sq. yard (sq. meter) times the areas of exposed faces of shoring constructed at the locations shown on the plans. Areas will be determined from measurements taken in the plane of the exposed face of the shoring.